# IMPROVING THE EFFICIENCY OF VORTEX DUST CATCHERS FOR FOOD INDUSTRY

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***ABSTRACT***

The critical factor that affects the overall efficiency of dust separation process in the apparatus with counter swirling flows is the inhibitory effect that leads to the drop in axial velocity of the dusty air flow.

The structural changes in the separating cylindrical chamber have been suggested based on the equation of moment of momentum for the input flows in the apparatus with counter swirling flows. They allow avoiding the inhibitory effects and increasing the efficiency by ensuring the same ratios between the costs and angular momentum for the input flows.

The velocity fields in the improved the apparatus with counter swirling flows have been determined through the experiment. It has been confirmed that the intensification of solid particles separation from dusty air is due to the velocity increase in all chamber holes at 30...50% in comparison with the typical the apparatus with counter swirling flows model.

By improving the design of the apparatus with counter swirling flows the collection efficiency has been increased by 5.2%.

***Key words:*** Improvement, Dust catchers, Efficiency, Equipment, Flow, Research.

***INTRODUCTION***

Food industry of Ukraine has been significantly renovated and updated for the last decade. It has greatly broadened assortment range of production and increased its quality. The topical issue of national economy further development is to expand foreign markets for the products. It requires a new stage of reconstruction and technological modernization of food enterprises' production capacities especially machine engineering.

One of the common apparatuses in food industry is dust catcher. Dry matter cleaning is very relevant nowadays, since the product yield depends on the efficiency of separation of dispersed particles from dusty gases. But the widespread centrifugal devices are rather expensive ones, moreover they do not provide 100% yield of a pure product. The centrifugal dust catchers – cyclones are most commonly used in technological processes. They are easy to manufacture and operate, but do not capture the particles smaller than 10 μm, and the total dust catcher efficiency is around 80%. New vortex dust catchers - apparatuses with counter swirling flows (ACSF) reduce the lower edge of trapped particles to 3...5 μm and their efficiency is more than 90%, but these apparatuses need deeper study.

The apparatus with counter swirling flows can be used instead of cyclones TSN-15 and TSN-15U for catching dust of different foods maintaining their quality for further use in the food industry, for example, to catch dust of sugar, casein, instant coffee, cocoa, vinasse, dried beet pulp, dried milk and other pulverized food products after drying, the flour from the pneumatic conveying line and as the first stage of purification in aspiration systems and pneumatic transport of grain processing enterprises. Their implementation will allow to improve the apparatus productivity, to reduce installations dimensions and their energy consumption [1].

ACSF as multipurpose apparatuses are used for drying bulk granular materials, separating gas-and-liquid heterogeneous mixtures, drying pastes and concentrated suspensions on the inert bodies, granulating products and fine materials: organic dyes, pigments, fertilizers, food products, pharmaceuticals, and for high-temperature processes of polydisperse system processing [2].

Despite the increased implementation of vortex apparatuses, there is no data on the complete replacement of traditional technologies: settling, filtration, use of straight-through vehicles etc. It can be explained by the lack of reliable methods for calculating processes which occur in the vortex chambers. It suggests the need to continue their study.

The analysis of publications of Russian and foreign researchers, such as P.M. Mikhailov, A.S. Belousov, B.S. Sazhin, A.R. Yakuba, D.F. Cilliberti etc., indicated that the issues of mathematical modeling the separation process of particles in the system of counter swirling flows (CSF), as well as the ways of constructive improvement have not been considered sufficiently.

All the above cited facts determine the relevance of the chosen topic of the paper, aimed at research of the separation of solid particles and increase of overall capture efficiency in the apparatus with counter swirling flows by their constructive improvement.

## *MATERIALS AND METHODS*

### Design of a vortex dust catcher

Apparatuses with counter swirling flows (ACSF) are multifunctional devices used for separating gas-and-liquid heterogeneous mixtures [3], drying granular and bulk materials [4], granulating products [5] and catching a wide range of dust in the chemical, food, pharmaceutical and other industries where there is a necessity of gas cleaning preserving the quality of collected dust for future use.

A vortex dust catcher (Fig.1) works as follows: a dusty gas enters into the body simultaneously through the central axial input 3 with a swirler 4 and the tangential or snail external input 2 of the gas flow. The secondary flow, which is supplied through the swirler 2, moves from the upper part of the body 1 down. While moving it gradually mixes with the axial flow, which moves upward through the swirler 4 between the two conical shells 10 and 11 through the hole 13.

While lifting up the lower axial flow mixes gradually with the outside flow and they enter the output pipe 5. In the polluted gas stream, which rotates under the centrifugal force, the suspended particles of dust rush toward its periphery, and thence, together with the secondary flow, descend down walls to the conical shell 10, and along the hole 16, between the shells 10 and 15 are poured into the conical bunker 6, and then into the container.

There are the following disadvantages of modern ACSF. They have smaller dimensions of the lower axial swirler of the primary flow than in the secondary flow supplied in the upper part of the dust catcher body, consumptions of flows are $L_2 : L_1 = 2:1$ and the angular momentum - $M_2 : M_1 = 4:1$. This leads to the fact that the input inhibits internal rotation, reducing the rotation velocity of the stream both throughout all the volume of the dust catcher and in the inner layer, which ultimately reduces the efficiency of the dust catcher [6].

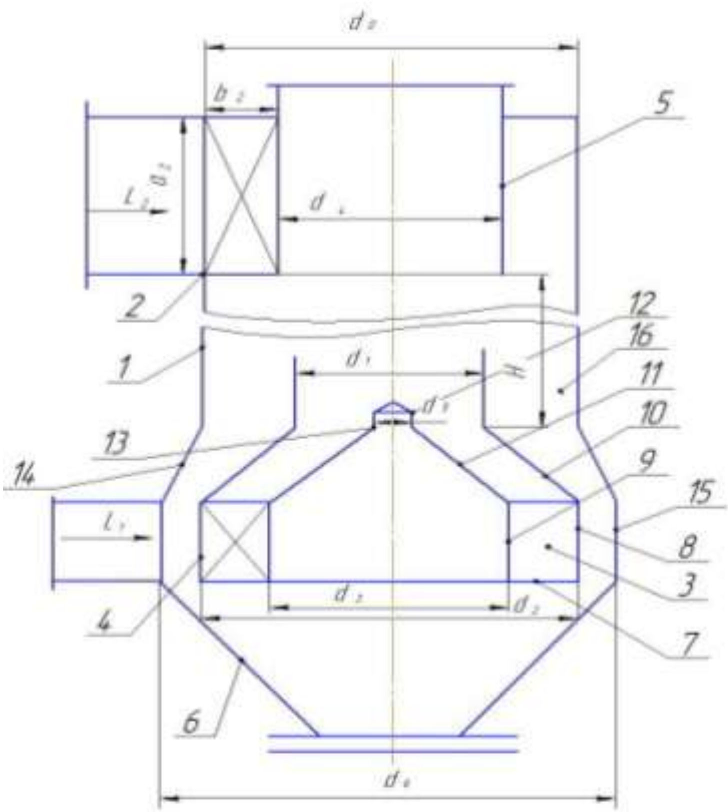



Fig. 1 The improved vortex dust catcher (with two cones): 1 - body; 2 - snail input of the secondary flow; 3 - the central axial input; 4 - the swirler primary flow; 5 - pipe for output; 6 - conical bunker; 7- flat bottom shim; 8 - the outer shell; 9 - the inner shell; 10, 11- conical shells; 12 - fairing flow; 13 - hole; 14,15 - shells body;16 - hole between the shim and the body of the dust catcher.

**The goal of development**

The goal of development of an improved dust catcher was to increase the efficiency of dust catching through balancing the ratios of flows and angular momentum.

Constructively it can be achieved by extending the diameter of the bottom and the bottom axial swirler and making two covers in the shape of truncated cones, instead of a flat cover to direct gas flow.

The moments of momentum can be calculated according to equations for the tangential and scroll swirlers [6]:

$$M_{input1} = \frac{2}{3}\rho_{gas} L V_{input} \frac{r_{external}^3 - r_{internal}^3}{r_{external}^2 - r_{internal}^2}, \tag{1}$$

where $\rho_{gas}$ is gas density, g/m$^3$;

$V_{input}$ is face velocity, m/s;

$r_{external}, r_{internal}$ are external and internal radii of a washer (for primary stream), m.

And

$$M_{input\,2} = \frac{2}{3}\rho_{gas} L V_{input} \frac{r_{case}^3 - r_{\text{output pipe}}^3}{r_{case}^2 - r_{\text{output pipe}}^2}, \tag{2}$$

where $r_{case}, r_{\text{output pipe}}$ are the radii of the body of the dust catcher and exhaust pipe (for a secondary stream), m.

Inserting the increased sizes of the external and internal radii of the washer, the input torque of the gas flow in the first entrance channel will increase, with input torque in the second channel being constant, thereby the equal ratio of the moments of gas movement to the flows expenditures will be achieved (in the theory). With the input torque of the primary flow being increased, the total time and the angular velocity of gas rotation will also increase:

$$C_0 = \frac{2M_{input}}{\rho_{gas} \cdot L_3 \cdot r_4^2}, \tag{3}$$

where

$\rho_{gas}$ is gas density, g/m$^3$;

$V_{input}$ is face velocity, m/s;

$r_{case}, r_{\text{output pipe}}$ are radii of the body of the dust catcher and exhaust pipe (for secondary stream), m.

And efficiency [7]:

$$\eta_{middle} = d^2 * \frac{2\pi\rho C_0^2 r_*^4 (r_0 + r_*) f(H)}{9\mu L_3^2 (r_0 + r_{mid})(r_0{}^2 + r_{mid}{}^2)} + \frac{(r_{mid}^2 - r_0^2) r_{mid} f(H)}{2(r_0 + r_{mid})(r_0{}^2 + r_{mid}{}^2)(r_0 - r_*)}, \tag{4}$$

$d$ is the particle diameter, m;
$\mu$ is coefficient of air dynamic viscosity, PA$\cdot$s;
$L_3$ is total flows' consumption in two channels, m$^3$/h;
$r_*$ is the border radius of split streams (a constant value), m;
$r_0$ is radius of the body of the dust catcher (a constant), m;
$r_{mid}$ is average radius of flow (a constant for each of the units), m;
$H$ is height of a separation zone of the apparatus, m,
but it is theoretically [8].

**The definition of velocities' fields in the separating chamber**

The experiment showed that the increase of such velocities as absolute, radial, tangential, and especially axial in separating cell apparatus will increase the efficiency of dust catching.

Velocity measurement was carried out pneumatically using a five-channel probe – a ball with the diameter of 5 mm with five holes drilled on two diametric planes perpendicular to each other. The ball was placed on the cylindrical rulers. The angle between the central axis and each of the side openings was 40°. Each of the holes was connected by means of thin tubes inside the holder. Each of the output probe holes was connected with the manometer. The probe installation in the set point of the apparatus was performed by the traversing gear. The depth of the probe immersion into the apparatus (by radius) changed from the wall to the center of the body, depending on the height of the traversing gear placement, with intervals of 25 mm. The velocity direction was determined by alternating rotation of the device in three mutually perpendicular planes around the center of the ball. The rotation proceeds until the same pressure was set in the paired lateral openings of the probe [1].

Calculation of velocity was carried out according to formulas, based on the critical analysis of known methods of determining velocities' fields. The measurement method is the most accurate. In addition, it is the simplest one for the experimental data processing [9].

The studies were conducted on three devices: a typical ACSF, the improved ACSF (with a single cone), the improved ACSF (with two cones).

ACSF efficiency was determined by pollinating the air with 50g of dry milk simultaneously through two channels within 50 seconds. Since, structurally, the secondary nozzle is twice larger than the original one, the secondary nozzle ACSF with the length of $a_2 = 0,09m$ has got $G_1 = 35g$ of the product while the original one with the length of $a_1 = 0,045m - G_2 = 15g$ .

The efficiency was determined on the basis of the ratio of weight of milk powder collected in the hopper of ACSF ($G_{\text{collected}}$) to the weight of milk powder entered the apparatus ($G_{enters}$) during the experiment ($\tau$) [10]:

$$\eta_{collected} = \frac{G_{collected}}{G_{enters}} \cdot 100\%, \tag{5}$$

where $G_{\text{collected}}$ is the weight of milk powder in the hopper, g ;

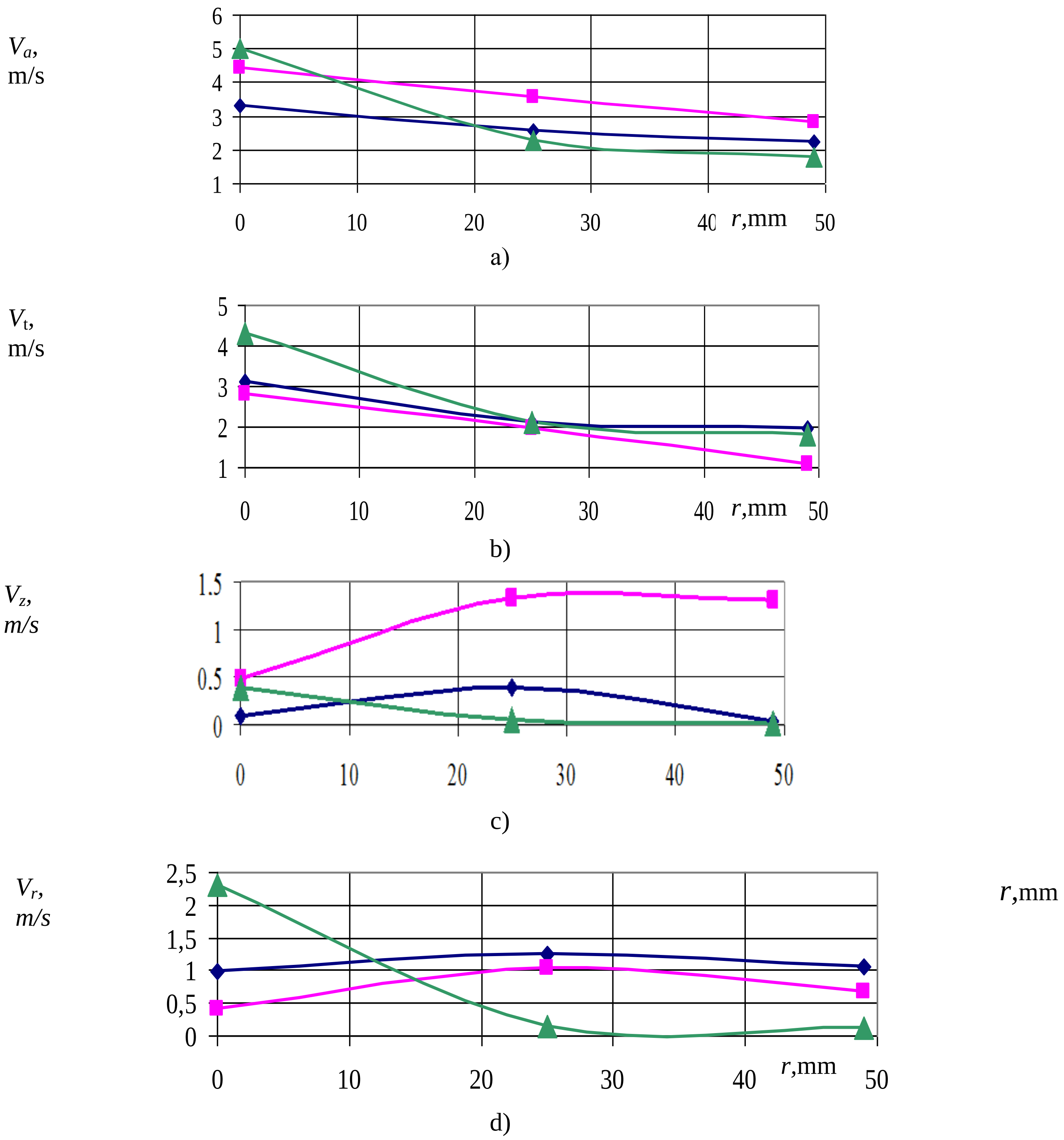
$G_{enters}$ is the weight of milk powder entered the apparatus, g.

But the effectiveness of ACSF determined this way does not give a complete picture of the number of small particles taken out with purified air. Therefore it would be reasonable to introduce the concept of the efficiency of particles collected by the apparatus ($\eta_{collected}$), which is equal to the ratio of the weight of milk powder fine particles taken out from the apparatus to the atmosphere $G_{\text{taken out}}$ to the weight of milk powder which enters it $G_{enters}$ .

## *RESULTS AND DISCUSSION*

### The velocities' fields

The increase of the input of angular momentum in the primary flow contributed to the increase of velocity in the separating chamber of the dust catcher. First of all, it was the axial velocity that increased, which is confirmed by the corresponding graphs below, based on the results got in the middle hole of the apparatus. The measurement distance h=170 mm from the exhaust pipe.




a) the module of absolute velocity $V_a$; b) tangential velocity $V_t$; c) axial velocity $V_z$; d) radial velocity $V_r$; ♦ - the flow rate in a typical ACSF; ■ - the flow rate in the improved ACSF (with two cones); ▲ - the flow rate in the improved ACSF (with a single cone)

Fig. 2. Graph of velocities measured in the second hole of the apparatus:.

The description of velocity graphs with the measured distance of h=170 mm from the exhaust pipe:

– the graph of the absolute velocity module $V_a$ of particles on the axis in the improved ACSF (with a single cone) is the largest, but falls sharply two times on the way to the periphery, while $V_a$ of the particles in the improved ACSF (with two cones) exceeds $V_a$ of the particle in a typical ACSF and reduces gradually on the whole way to the wall;

– the graph of tangential velocity $V_t$ of solids in the improved ACSF (with a single cone) is the largest on the axis and decreases slowly to the periphery, and $V_t$ of the solid particles in the improved ACSF (with two cones) is close to $V_t$ of the solid particles in a typical ACSF and at the distance of 25mm from the apparatus wall is almost equal to $V_t$ of the solid particles in the improved ACSF (with the single cone);

– the graph of the axial velocity of particles in the improved ACSF (with two cones), as well as with the measured distance h=130 mm from the exhaust pipe, has the highest axial velocity which reaches its maximum at the distance of 25mm from the wall, $V_Z$ of the particles of the other two devices is irregular;

– the graph of radial velocity of particles on the axis in the improved ACSF (with a single cone) has the maximum radial velocity, but in the middle of the traversed path it sharply reduces and becomes lower than $V_r$ of the particles in the improved ACSF (with two cones) and a typical ACSF, which decreases slowly [1].

The measurement error of costs made up 7-8%. The deviation of the absolute velocity module from the average number of nine experiments did not exceed 10%, the measurement error of the angle between the velocity vector and the horizontal axis was 2.5%. In this regard, the error of determining the axial and radial velocity was 10-15%, the tangential velocity – 7-10%. The results of the experiments are depicted in the graph (Fig. 2). The axis of ordinate represents values of velocities $\bar{V} = V / V_{middle}$, and the X-axis demonstrates the relative radius $\bar{r} = r / r_0$.

**The efficiency of ACSF**

After the experiments, the hoppers of each ACSF were discharged giving three samples of the unloaded product.

According to the equation (5), the efficiency of dry milk capture by a typical ACSF and the improved ACSF is the following [11]:

– a typical ACSF: $m_1 = 47,2g$ , $\eta_1 = 94,4\%$;

– the improved ACSF (model 1 with two cones): $m_2 = 49,8g$ , $\eta_2 = 99,6\%$;

– the improved ACSF (model 2 with a single cone): $m_3 = 49,3g$ , $\eta_2 = 98,6\%$.

***CONCLUSION***

The increase of the input of angular momentum in the primary flow by half enhances the flow velocity in the separation space of the apparatus, increasing separation of the dust (of the product) from gas thereby improving the efficiency of dust catching. Thus, the efficiency of the improved ACSF increased by 5.2%.

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